Control and Data Fusion eJournal: CADFEJL Vol. 1, No. 3, pp. 25-32 May-Jun 2017.

# Electro-Mechanical Actuator: A Simulation Study

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**Abstract:** Electro-Mechanical Actuator (EMA) modeling and simulation using Simulink block set has been implemented and tested with input step and repeated sequences. The results obtained from this simulation are satisfactory. This simulation model can be used for developing EMA health condition monitoring techniques and educational purpose. Basically a simplified and complete Simulink based approach is presented.

Keywords:- More electric aircraft, electro-mechanical actuator, Simulation, Simulink

## 1. Introduction

Off late, aircraft uses a combination of pneumatic, hydraulic, and electric systems. Future aircrafts will have electrical system and electrically powered equipment's. This is called More Electric Aircraft (MEA), power-by-Wire, or All-Electric-Aircraft (AEA) where the power is transmitted through wires between the systems [1, 2]. This technology reduces the maintenance, increase the efficiency, and have more fault tolerant systems. One of the main systems in the MEA is electric actuation system that deflects the flight control surfaces such as rudder, aileron, spoiler etc... These actuators are either electro-hydrostatic actuator (EHA) or electro-mechanical actuator (EMA). EMA is a good candidate for electrical flight control actuation [3]. EMA is used for a spoiler surface on B787. In general, EMA consist of Brushless Direct Current (BLDC) motor coupled to a ball or roller screw through a reduction gearbox. There are two types of EMAs, some produces rotary motion and other produces linear motion outputs. More research is going on worldwide to enlarge and mature EMA technology [4]. In this paper, EMA modeling and simulation using Matlab Simulink blocks [5] are presented and demonstrated. Contribution in this work is, making a simple EMA working model and simulation for educational purpose and for developing techniques for EMA health condition monitoring,

## 2. Electo-Mechanical Actuator (EMA)

EMA is combination of position Proportional-Integral-Derivative (PID) controller, BLDC motor drive, reduction speed gearbox, ball, or lead screw as shown in Figure 1. The error between the pilot input and the actuator position is given to the position PID controller. PID used in this simulation is shown in eqn.1. The output of this controller ($S(n)$) is given to BLDC drive and motor. Motor will run at desired speed given by the position PID. Motor rotation direction and speed allows the EMA to move the mechanical surface to the pilot (input) demand. Since motor runs at very height speed, reduce gearbox is used to reduce the speed and it drives the lead screw. Motor currents controls mechanical output to the control surface [6]. Lead screw converts rotational motion into linear motion and it drives the actuator. Actuator deflects the flight control surface. Actuator have position sensor that gives angular position measurement of the actuator.

The PID position controller has the following parameters:

$$S(n) = Pe(n) + \frac{I}{s}e(n) + \frac{DN}{1+\frac{N}{s}}e(n) \qquad (1)$$

Where

$S(n)$ : Speed at $n^{\text{th}}$ instant (rpm)

$e(n)$ : Error speed at $n^{\text{th}}$ instant (deg.)

$P$ : Proportional co-efficient
$I$ : Integral co-efficient
$D$ : Derivative co-efficient
$N$ : Filter co-efficient

The internal sub-systems of BLDC drive and motor is shown in Figure 2. It has both speed and current controllers. Speed controller regulates the speed. BLDC motor runs with alternative current (AC) and hence three-phase inverter has been used to convert DC power into AC power and fed to the motor. Inverter have on and off switching devices to convert DC into AC. DC of 28VDC is used in this work since the aircraft electrical systems works at this voltages. These switching devices are controlled by gate pulse generated from current controller. Phase currents and hall sensor measurements are used to generate gate pulses. Rotor speed (rad/s) is the output of the motor. This speed is multiplied by a factor of $30/\pi$ to get the rpm and is given as an input to gearbox. The sub-blocks of gearbox are shown in Figure 3. It reduces the speed by factor of gear ratio and it drives the lead screw. Gear ratio of 6.25 is used in this study. The lead screw sub-system in shown in Figure 4. It translates the rotation motion into linear motion. Displacement per revolution is 0.15 used in this work. Aileron model has been taken from Ref. [7, 8]. It deflects the surface based on the output of lead screw. It has a position sensor that gives the measurement (deg.) that will be used for speed controller.

EMA performance is evaluated using percentage fit error (PFE) and it can be expressed as:

$$PFE = 100\frac{norm(i-a)}{norm(i)} \qquad (2)$$

Where $i$ : input signal
$a$ : Aileron response

## 3. Results And Discussion

The EMA specification and PID parameters used in this simulation are shown in Tables 1,2. The input (pilot stick) signal and the actuator response are shown in Figure 5. It is observed that there is some error during the transition from $0^0$ to $30^0$ (at 0.5sec.) and the error reduce with time. It is because of EMA processing and inertia of mechanical parts. The error can be reduced by tuning the PID controller. The actuator response for $0^0$ and $30^0$ input signal can be seen in Figure 6. The demanded speed ($S(n)$) at the output of speed controller is shown in Figure 7. It is observed that at the time of transition, it demands very high speed. The zoomed version of Figure 7a is shown in Figure 7b. It is observed that speed demands gradually reduce when the aileron reaches the required position. Stator currents, hall sensor measurements, torque, and gate pulses are shown in Figure 8. Motor draws more power that is electric at transition $0^0$ and $30^0$ (at 0.5sec); Hall sensor provides measurements that are used to generate gate pulse.

EMA performance has been tested with repeated sequence [7]. Repeated sequence input generator parameters are shown in Figure 9. The repeated sequence input and aileron response are shown in Figure 10. There is a little visual error while the input signal is ramp phase. It is due to delay in the process as expected. It is observed that EMA responds to the input signal and follows the input sequence. EMA performance in terms of percentage fit error is show in Table 3; the PFE for step input compared to repeated sequence is a little higher. It is because of aileron mechanical inertia (and motor, gear and leadscrew. It is a just metric to choose best tuning PID parameters. Also, the PFEs are high, because the initial transient response is included in the computations. EMA performance, with different position PID controller parameters (Table 4), is shown in Figure 11 and error that is the difference between the reference input signal and aileron response are shown in Figure 12. PID parameters, corresponding legend used for identification and PFEs are shown in Table 4. It is observed that p20i0d0 (P=20, I=0 & D=0) shows an overshoot in response and taking more time to settle followed by p10i0d0. Response with p1i0d0 and p10i1d0 took more time to settle without overshoot. There is no overshoot in p10i1d1.5 but it take little more time while compare to p10i0d0. The responses with p10i0d0 & p10i1d0 shows little overshoot but settle very fast. Same observations made from Table 4.

## 4. Conclusion

Electro-Mechanical Actuator (EMA) modeling and simulation using Matlab Simulink block set has been implemented and tested with input step and repeated sequences. The results obtained from this simulation are satisfactory. This simulation model can be used for developing EMA health condition monitoring techniques and educational purpose. The simulation model can be obtained from the following link:

https://in.mathworks.com/matlabcentral/profile/authors/1612307-vps-naidu

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Table 1: EMA specification used in this simulation

| Parameter | Values |
|---|---|
| Stator phase resistance (R) | 0.2 (ohm) |
| Stator phase inductance (L) | $8.5\text{x}10^{-3}$(H) |
| Flux linkage | 0.175 |
| Phases | 3 |
| Pair of poles | 4 |
| Back EMF | trapezoidal |
| Power supply | 28VDC |
| Sample time | $2\text{x}10^{-6}$ |
| Gear ratio | 6.25 |
| Screw (displacement per revolution) | 0.15 |

Table 2: PID parameters

| **Speed controller parameters** | |
|---|---|
| Proportional co-efficient | 1.5 |
| Integral co-efficient | 50 |
| Low pass filter cut-off frequency | 125Hz |
| **Position controller parameters** | |
| Proportional co-efficient | 10 |
| Integral co-efficient | 1 |
| Derivative co-efficient | 1.5 |
| Filter co-efficient | 100 |

Table 3: Percentage fit error for different inputs

| Input signal | PFE (%) |
|---|---|
| Step input | 29.21 |
| Repeated sequence | 13.84 |

Table 4: PFE for different position PID controller parameters

| PID parameters | | | legend | PFE (%) |
|---|---|---|---|---|
| P | I | D | p1i0d0 | 43.6 |
| 1 | 0 | 0 | p10i0d0 | 27.97 |
| 10 | 1 | 0 | p10i1d0 | 28.16 |
| 10 | 1 | 1.5 | p10i1d1.5 | 31.99 |
| 10 | 1 | 5 | p10i1d5 | 45.29 |
| 10 | 10 | 0 | p10i10d0 | 30.79 |
| 20 | 0 | 0 | P20i0d0 | 39.13 |

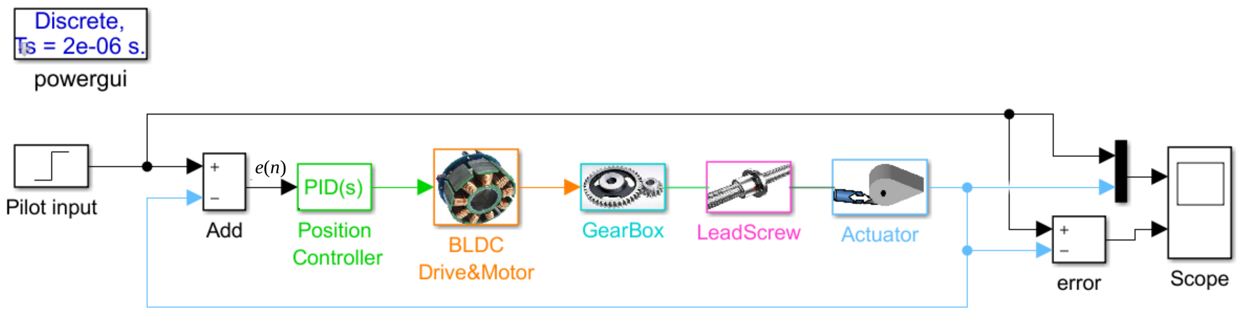


Figure 1: Information flow diagram of electro-mechanical actuator

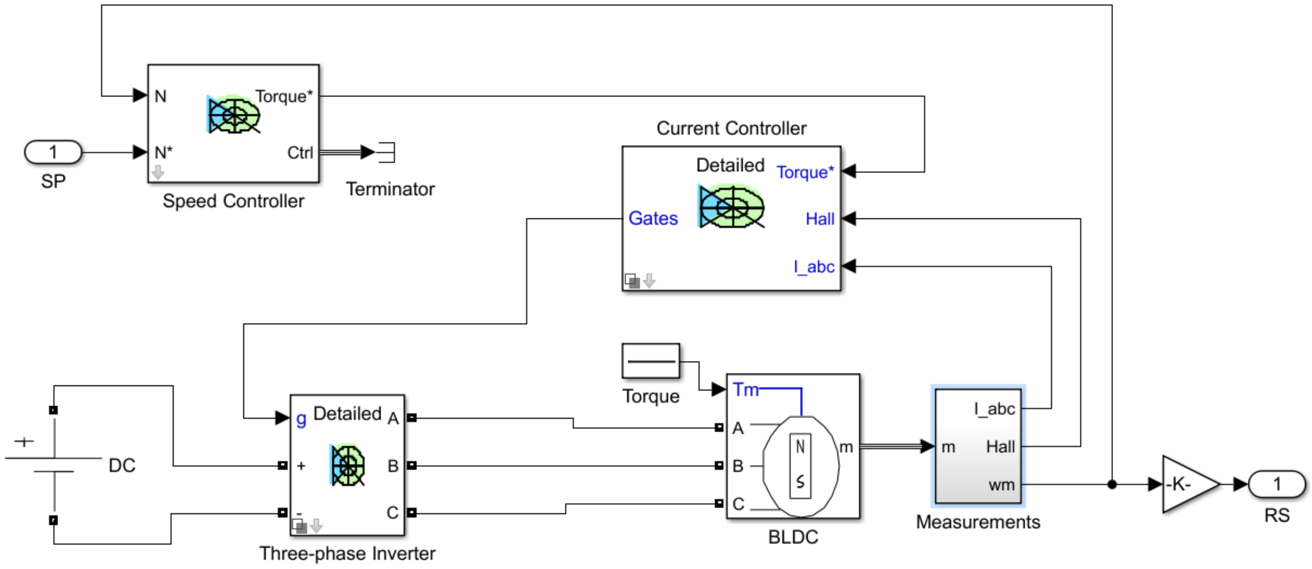


Figure 2: BLDC drive and motor internal sub-blocks

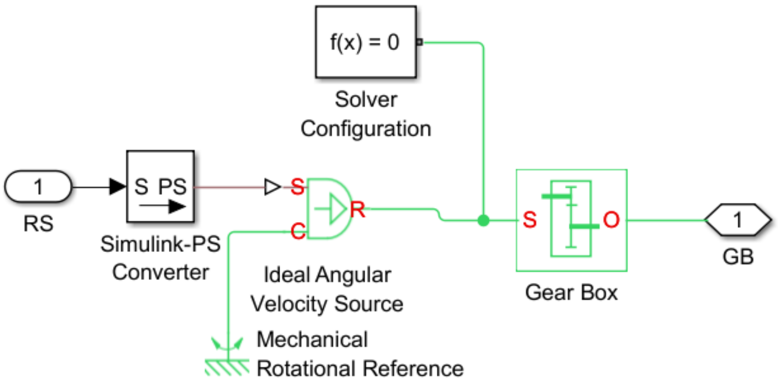


Figure 3: Gearbox mechanism

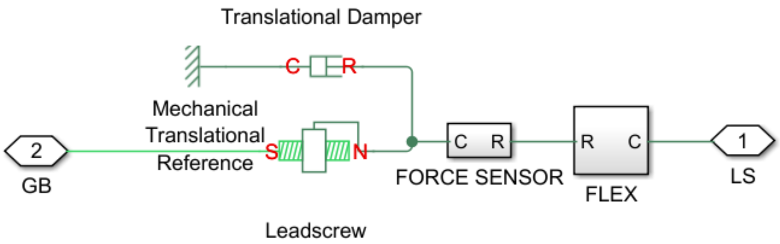


Figure 4: Lead screw mechanism

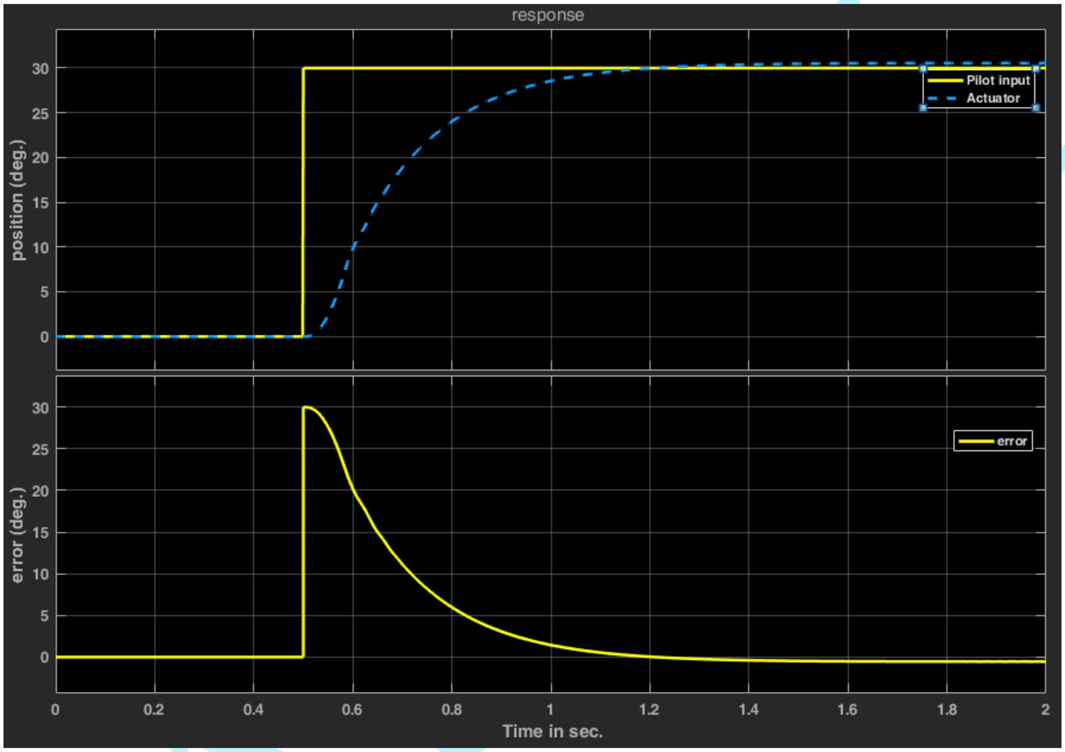


Figure 5: Input and actuator response

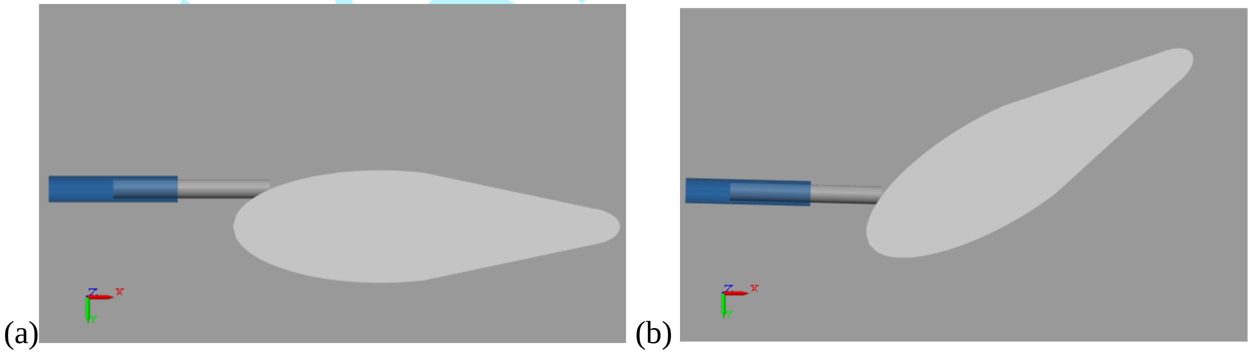
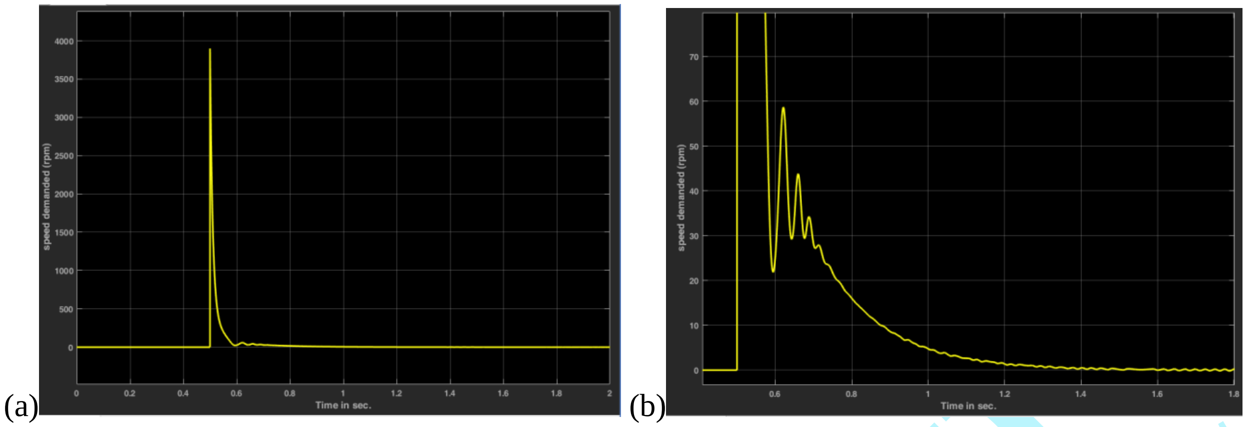


Figure 6: (a) Actuator position at $0^0$ and (b) Actuator position at $30^0$



(a) (b)

Figure 7: (a) demanded speed and (b) zoomed version of (a)

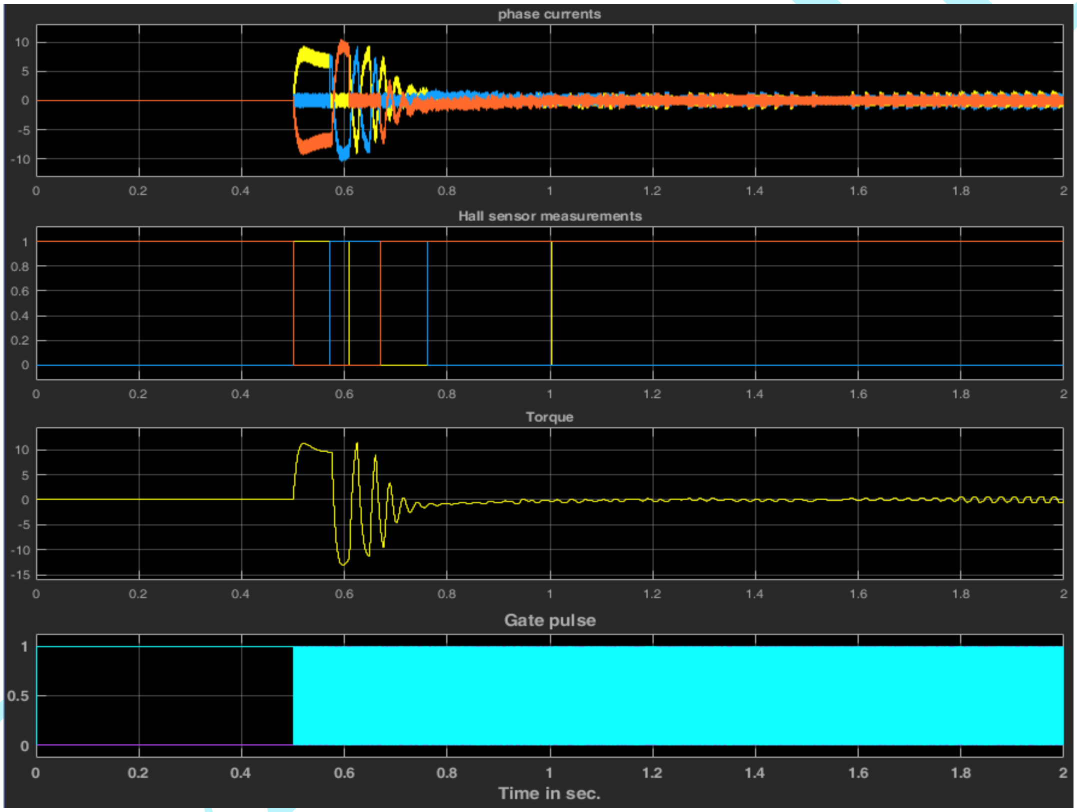
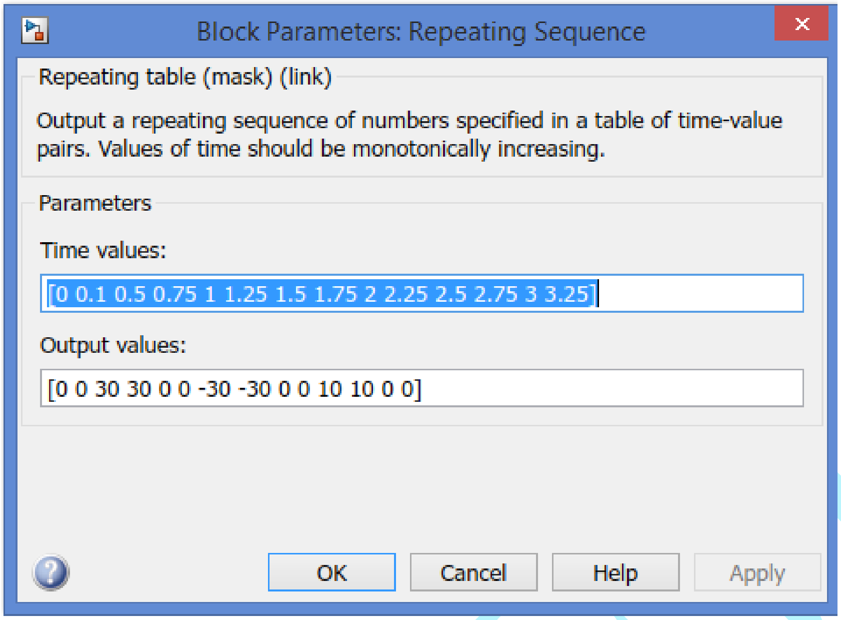


Figure 8: Stator currents, hall sensor measurements, torque and gate pules



Repeating table (mask) (link)

Output a repeating sequence of numbers specified in a table of time-value pairs. Values of time should be monotonically increasing.

Parameters

Time values:

[0 0.1 0.5 0.75 1 1.25 1.5 1.75 2 2.25 2.5 2.75 3 3.25]

Output values:

[0 0 30 30 0 0 -30 -30 0 0 10 10 0 0]

Figure 9: Repeated sequence input generator parameters

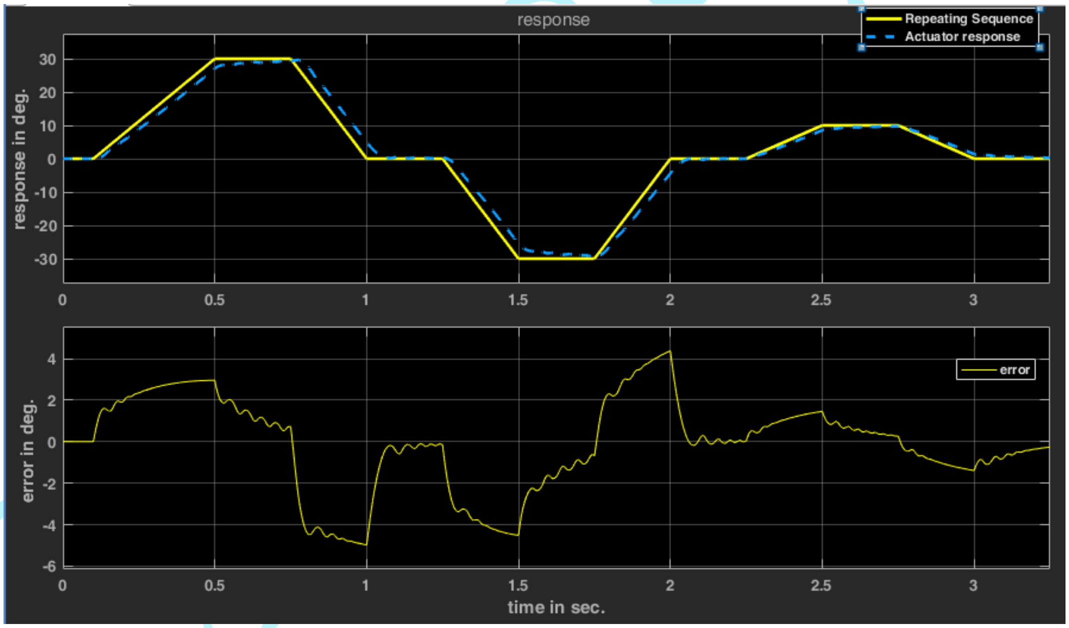


Figure10: Repeated sequence input and aileron response

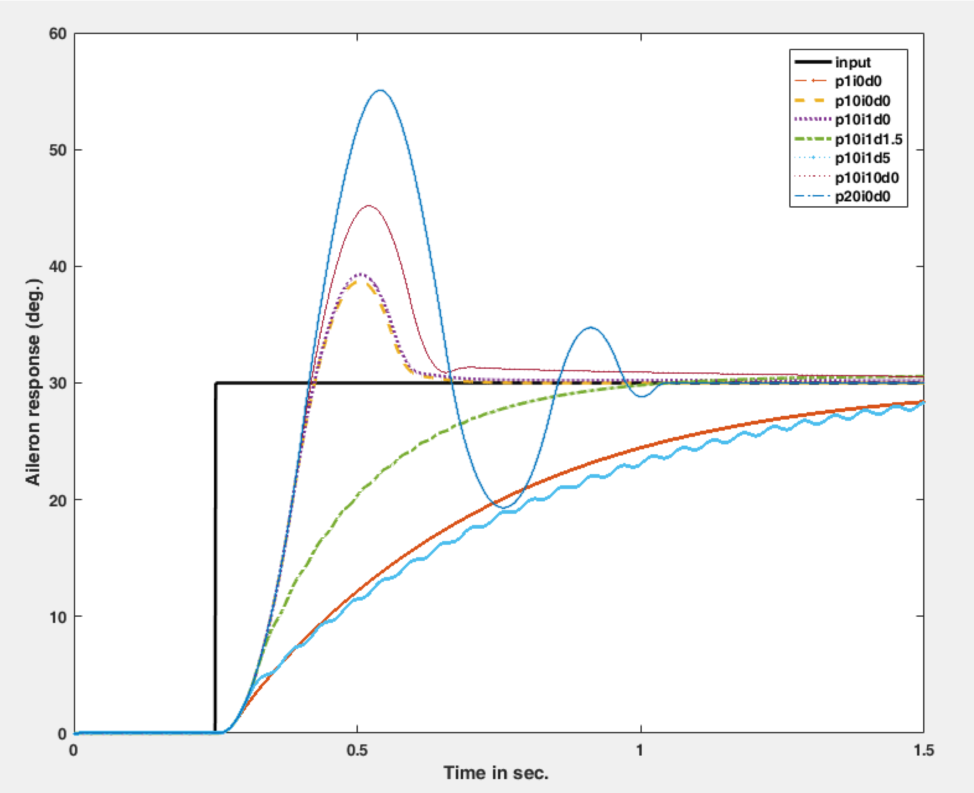


Figure 11: Aileron response with different PID parameters

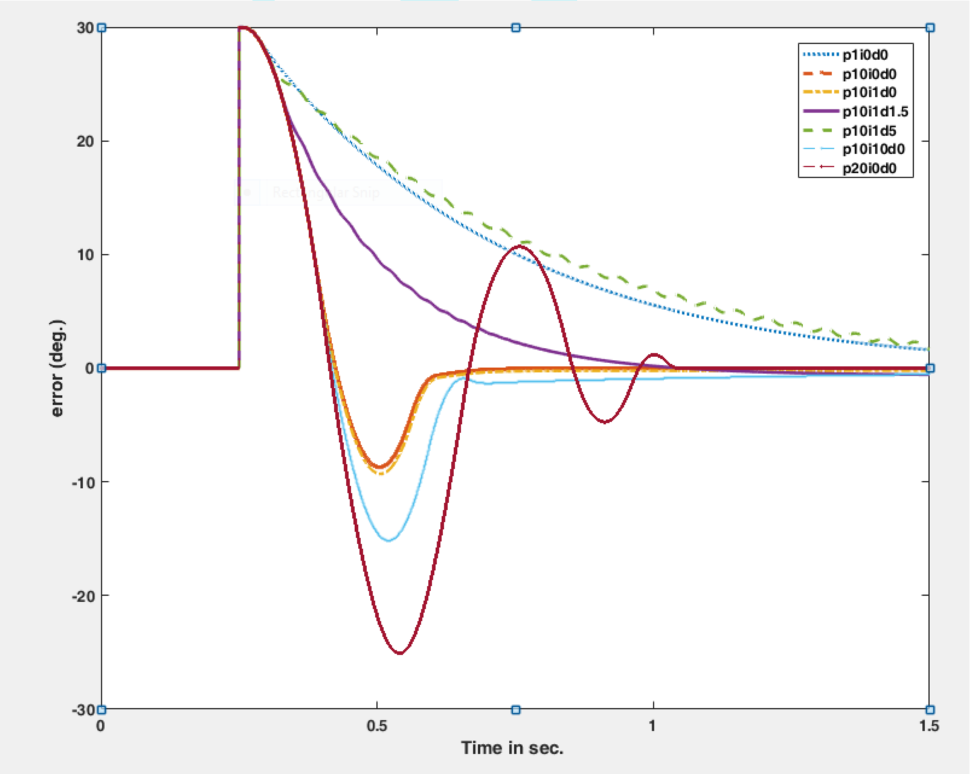


Figure 12: Error with different PID parameters